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Bluetooth Low Energy Indoor Positioning System

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Bluetooth Low Energy Indoor Positioning System Abstract

Robust indoor positioning systems based on low energy bluetooth signals will service a wide range of applications. We present an example of a low energy bluetooth positioning system. First, the steps taken to locate the target with the bluetooth data will be reviewed. Next, we describe the algorithms of the set of android apps developed to utilize the bluetooth data for positioning. Similar to GPS, the algorithms use trilateration to approximate the target location by utilizing the corner devices running one of the apps. Due to the fluctuating nature of the bluetooth signal strength indicator (RSSI), we used an averaging algorithm to smooth the data, increasing the reliability in the calculated target location. The system produces target coordinate locations relative to the distance from the corner applications in the room containing the target; under ideal conditions, the corners can be up to around 80 meters apart. The system produces accurate target locations 85% of the time, as in the calculated location of the target is within about 40 cm to the actual location of the target. This was found in the test environment of a rectangular room of 2.5 by 3.5 meters. The relative coordinates were found to be about 40 cm apart, with about 20 cm of error per coordinate set for this system's scale. The system is able to track typical walk speeds and relative movement between the different corner devices efficiently and accurately enough to provide useful information for real world situations.

BLE Indoor Positioning System Research Annotated Bibliography

T. L. Floyd, *Digital Fundamentals*. Essex: Pearson Education, 2014.

This book is used in my Computer Logic & Circuit Design class which was a critical class towards understanding the ideas for this project. This book gives me reference to the fundamentals of all the hardware and software I would be using in my project. It will give me background information and help inform me on what hardware would work best for this kind of set up in my project. It includes how to implement different types of logic gates and systems to create a more efficient and reliable system. These are the kind of things that would be crucial to optimizing my project further by implementing simpler computers like raspberry pis or arduino boards that could execute the code more efficiently. This text will be useful as I continue to work on this project and adapt it farther.

F. S. Danis, A. T. Cemgil, and C. Ersoy, "Adaptive Sequential Monte Carlo filter for indoor positioning and tracking with bluetooth low energy beacons," *IEEE Access*, vol. 9, pp. 37022–37038, Mar. 2021.

This paper is about a similar project to mine in that they only used a form of the RSSI bluetooth signal to track their targets. They work under the same assumptions that the RSSI is the only form of data they will get from the target, however they have a different process to adjust the reading relative to the setup of the system. They relied on using a fingerprint system where real values for the room are measured to help estimate the location of the target. On top of that, to adjust the values they use a three layer hidden Markov model, which is a mathematically different approach to the tracking model that I employed.

A. K. Taşkan and H. Alemdar, "Obstruction-aware signal-loss-tolerant indoor positioning using Bluetooth Low Energy," *Sensors*, vol. 21, no. 3, p. 971, 2021.

The methods that are used in this paper for indoor positioning are extremely similar to what I am doing fine. They combined a multilateration with fingerprinting to create a highly accurate model that they then were able to test with. This approach is a more sophisticated version of what I'm aiming to achieve with my project. They were able to produce accurate results within approximately 2 meters of error in a realtime busy environment. Being able to achieve similar results for my project will be an excellent goal for me to set. They were able to demonstrate the effects different environments can have on the reliability of the RSSI signals. The OASLTIP system they developed has additional sophistications that my project could add to it to improve upon it farther. This shows there are many similar approaches to solving the same problem.

L. Bai, F. Ciravegna, R. Bond, and M. Mulvenna, “A low cost indoor positioning system using Bluetooth Low Energy,” *IEEE Access*, vol. 8, pp. 136858–136871, 2020.

An experiment is set up in an assisted living facility to test the usability of the two main approaches to indoor positioning that is RSSI based. These two methods being fingerprinting and a trilateration calculation. The experiments however used pre recorded data for tracking the user during them, which is different from the approach I used for testing. The paper goes on to show how effective a trilateration calculation can be and allow for professionals to gather more data on their clients to help them further. They also explore the different cost factors with different kinds of set ups for the system. This kind of research will be valuable in taking my project to the actual market.

H. Yao, H. Shu, X. Liang, H. Yan, and H. Sun, “Integrity monitoring for bluetooth low energy beacons RSSI based indoor positioning,” *IEEE Access*, vol. 8, pp. 215173–215191, Nov. 2020.

Since I will also be using a similar system to that of the one tested in this article, it will be valuable in proving predictions about my future results. The system implements a data integrity monitoring algorithm to predict its own calculations in real time just like mine would. They take in RSSI readings and use the Least Square Base of the Taylor expansion to calculate the position for the target. I may be able to take inspiration from how their algorithm adjusted to the real time data and use it for my own project. They were able to achieve accuracy for tracked objects within 2 meters just like I plan to do.

P. Zhao, L. Wang, Y. Tian, L. Guo, and B. Lu, “WiFi-Bluetooth Dual Modal Indoor Positioning System Using Adaptive Range Filter” *CSDL | IEEE Computer Society*. [Online]. Available: https://www.computer.org/csdl/proceedings-article/bigcom/2021/425200a060/1xlA3qEL6Te. [Accessed: 12-Sep-2022].

This paper is able to create a result very similar to what I intend to accomplish with my project. By utilizing wifi and bluetooth low energy a system can be made using multilateration to accurately predict the target location most of the time. Through testing they are able to get results accurate within a meter for the location of a target 90% of the time. The filter processed used by the researchers differs from what I will use to filter my data because I have implemented a weighted average filter to read all the data received. This is another example that shows this technology is possible and is being developed currently for real world applications.

J.-sung Jeon , Y. Kong , Y. Nam , and K. Yim, "An Indoor Positioning System Using Bluetooth RSSI with an Accelerometer and a Barometer on a Smartphone" *CSDL | IEEE Computer Society*, 2015. [Online]. Available: https://www.computer.org/csdl/proceedings-article/bwcca/2015/8315a528/12OmNqJq4nw. [Accessed: 12-Sep-2022].

This paper takes a different approach to the indoor positioning problem by assuming that they are tracking a smartphone of a walking person. For their calculations they get additional data besides its RSSI value from the smartphone that gives real time statistics about its sensed movement. Between the accelerometer and barometer the vector of the pedestrian's direction can be calculated which they reference with the RSSI values to calculate the actual position. They implement a stop detection method with the RSSI values to see when the target is still or not still. This differs in approach to what method I plan to use to calculate the positions, but shows the variety of information and approaches that one could apply to solve the problem.

T. L. N. Nguyen, T. D. Vy, and Y. Shin, "Environment-Aware Tracking Scheme for Smartphones Based on BLE Beacons," *CSDL | IEEE Computer Society*, 2021. [Online]. Available: https://www.computer.org/csdl/proceedings-article/smartiot/2021/451100a021/1xDQgfn6Kkg. [Accessed: 22-Sep-2022].

This paper and research takes a similar approach to what I intended to accomplish with my project. It takes it a step farther by getting even more data from the smartphone by tracking its inertial measurements in real-time. This as well as the fine tuning model employed by the research allows for an extremely accurate tracking model in a real-time environment while using minimal sensors. They also build up a fingerprint database for each user they are tracking which will further assist in calculating the true positions more accurately. This approach however requires more input and intent from the user than mine who continually tries to take the best guess it can on where the target is. The paper shows that the old use of using a BLE proximity method with beacons is outdated and less efficient than more current models that are being employed.

R. Jérémy, B. Karell, and F. Cyril, “Ble based indoor positioning system and minimal zone searching algorithm (MZS) applied to visitor trajectories within a museum,” *MDPI*, 30-Jun-2021. [Online]. Available: https://www.mdpi.com/2076-3417/11/13/6107. [Accessed: 22-Sep-2022].

The article describes how approaching indoor positions using a minimal zone searching algorithm can be used to efficiently demonstrate indoor tracking inside a museum. The minimal zone searching algorithm is another approach to the positions by deciding pre-determined zones that the signals will fit into on their model which they then use to determine the position. The museum of natural history of La Rochelle was used in this paper for their experimentation with the help of local highschool students. The zones were found to be accurate within about 3 meters of each other which allowed for one to see clear movement and tracking of a target. The experiment was able to produce accurate results that depicted the location of the students constantly throughout the trials.

C. Ma, B. Wu, S. Poslad, and D. R. Selviah, “Wi-Fi RTT Ranging Performance Characterization and Positioning System Design,” *CSDL | IEEE Computer Society*, Feb-2022. [Online]. Available: https://www.computer.org/csdl/journal/tm/2022/02/09151400/1lPCnYPauPe. [Accessed: 22-Sep-2022].

The use of the commercial off the shelf devices is exactly like what I will be doing for my project. They utilize wifi and trilateration to process the data in order to track the target, however they implemented a variety of different systems to improve upon their system. First the read is determined if it is good or not before being used in calculation, then trilateration is used followed by a Kalman filter. With all of these improvements the system was able to achieve accuracy within 1.2 meters for static reading and 1.3 meters for dynamic ones. The readings generated by this approach are extremely accurate and demonstrate the usability of the technologie. This will be a useful guide in achieving a similar result and show me what kinda things I should account for in my readings like implementing a good tolerance to ranging errors from the fluctuating RSSI values.

G. Lee, S.-H. Jung, and D. Han, “An Adaptive Sensor Fusion Framework for Pedestrian Indoor Navigation in Dynamic Environments,” *CSDL | IEEE Computer Society*, Feb-2021. [Online]. Available: https://www.computer.org/csdl/journal/tm/2021/02/08868212/1e7BXfE8cOk. [Accessed: 28-Sep-2022].

This paper takes an entirely different approach to indoor positioning tracking by using primarily the internal readings from the different sensors on a smartphone. This system they designed is called the dynamic sensor fusion framework which utilizes the many different sensors built into smartphones like the accelerometer, the compass, gyroscope, and a combination of others to track the target. With this method it learns biases and patterns and is able to generate reasonably accurate data when tested in a single story or multiple story environment. It does this without the use of RSSI signals or beacons and simply communicates its estimated coordinates over wifi. This goes to show how the approach to getting the calculated position can be done in a variety of ways that utilize different features.

R. Tabata, A. Hayashi, S. Tokunaga, S. Saiki, M. Nakamura, and S. Matsumoto, “Implementation and evaluation of BLE proximity detection mechanism for Pass-by Framework,” *CSDL | IEEE Computer Society*, 2016. [Online]. Available: https://www.computer.org/csdl/proceedings-article/icis/2016/07550872/12OmNx8fiaM. [Accessed: 28-Sep-2022].

In this paper, the strength of BLE proximity detection is discussed and shown in real world applications. They reference the “TohakuNavi” system which is used in the Tokyo national museum to give information about each exhibit as a guest approaches it. They discuss the importance of setting specific parameters for the BLE system like I have done for mine to adjust the RSSI value to realistic coordinates. They ran experiments concerning a person’s walk speed to the detection of their position, with different parameters such as the detector’s position and the actual speed. This kind of data is exactly the same kind of thing I will be doing in my project.

Y. Chapre, A. Ignjatovic, A. Seneviratne, and S. Jha, “CSI-MIMO: Indoor Wi-Fi fingerprinting system,” *CSDL | IEEE Computer Society*, 2014. [Online]. Available: https://www.computer.org/csdl/proceedings-article/lcn/2014/06925773/12OmNzBOhLt. [Accessed: 28-Sep-2022].

This paper explores one of the main competitors in technique to my indoor positioning system. This system must take readings across its environment in order to build the environment virtually. This is a step that my technique completely forgoes making its setup much easier to do in practice. However, this system is able to produce highly accurate positioning information, more-so than my own. This is done by extracting fine-grained information that is able to assist in providing a more accurate location for the target in question. It highlights the main downside of using a RSSI based system to calculate positioning, in its unreliability. It shows how effective this system can be in a set environment as they were able to achieve reasonably accurate location data. This goes to show that there are a variety of approaches to solve this problem, that each have their own advantages.